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Preliminary
Feasibility Study

GUN CAMERA MISS DISTANCE INDICATOR

FINAL REPORT

R. Bruce Young
Jon R. Berry

September 1970

prepared for:

Weapons Branch, Systems Research Laboratory
Human Engineering Laboratories
USA Aberdeen Research and Development Center
Aberdeen Proving Ground, Maryland

by

AAI Corporation
BALTIMORE MARYLAND

Under Contract Number DAAD05-70-C-0394

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ERRATA

Pg. 3, under "Cyclic Rate" should read "The M14 is normally rated at about 20-30 rounds per minute ..."

Pg. 4, line 7, add "second" after ".008"

Pg. 19, line 8, add "which" after "attached".

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PRELIMINARY FEASIBILITY STUDY
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SUMMARY

A study was made to determine the feasibility of mounting a photographic device on a rifle so as to obtain a picture of the boresight point just prior to projectile exit. The photograph would be used to estimate projectile miss distance at ranges up to 500 meters under simulated tactical conditions. During the program the desired system performance specifications were established and alternative design approaches were evaluated.

It was concluded that it is apparently feasible to build a device, using present technology, which will meet the performance specifications. It is expected that the most difficult specification to meet will be the .75 pound weight limit, which corresponds to the weight of a bayonet for an M-14 rifle.

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I. INTRODUCTION

For years, military small arms studies have been reporting accuracy data in terms of hit probability - usually hits/shots (with the number of hits on a target determined either by visual inspection after a firing exercise or by electronic device which records hits or penetrations as they occur. For some time, the research community has acknowledged the artificiality of this expression as an accurate representation of the parameter of interest, namely "combat effectiveness." It is suspected that this parameter may be determined in part by the increasing proximity of projectile impact points to the intended target. At the moment, no one conducting small arms field research is able to measure accurately increasing proximity of ground impact points in a simulated tactical setting. There is a present requirement to obtain this information with an M-14 rifle fired semiautomatically from the prone position with tracer and ball ammunition under high and low ambient illumination.

One system concept for obtaining miss distance and direction measurements is to have a lightweight camera, mounted on and boresighted with the rifle, take a picture of the target area several milliseconds before each round is fired. The X and Y coordinates of the location of the center of the target within the picture taken just before a given round is fired are used to calculate an approximation of the miss distance of that projectile.

The objective of the study described in this report was to determine whether the concept of a gun-camera is - on its own merits and without regard to other miss distance indicator (MDI) concepts - likely to prove technically feasible and practical as an MDI and is worthy of further study by the Government at this time.

Prior to the present contractural effort, the Human Engineering Laboratories (HEL) made a preliminary survey of American manufacturers in an attempt to determine the availability of a camera which might satisfy the MDI requirement. Ten manufacturers responded to the inquiry and in all cases the response was negative. Furthermore, very little interest was expressed in pursuing the problem. One large manufacturer who indicated an initial interest in a development program withdrew his interest when subsequent discussions revealed that the Government's eventual requirements would probably be limited to about 100 units. (AAI received a similar negative response when we asked another manufacturer if he could supply a production item with a larger lens. A quantity of 100 was too small to be worthwhile to him.)

This background and responses to initial enquiries by AAI led to the conclusion that there was no camera on the market which would immediately satisfy the requirements. Further, camera manufacturers as a group seemed to have little to offer in terms of suggestions as to how a camera might be modified or designed to meet the requirements. AAI suspects that the lack of enthusiasm for the problem was due to two factors. First, the persons contacted were not familiar enough with weapons to fully understand the problem, and second, the demand for specialized cameras is so limited that the camera manufacturers do not maintain organizational structures capable of handling assignments of this type.

Since there did not appear to be an off-the-shelf item which would satisfy the requirements, the program was directed along a more basic approach of determining if cameras were available which would approach certain goals pertaining to weight, lens size, shutter speed, and film transport. Based on the information gained through this investigation, conclusions have been drawn as to the feasibility of blending and extending the capabilities of proven components to produce a photographic device which will perform the MDI function.

The ultimate objective of the overall program is to obtain information on weapons systems; not advance the state-of-the-art of photography. Therefore, this investigation was limited to considering essentially existing photographic capabilities. In the report reference is made to specific brand names. This format was adopted because knowledgeable readers will no doubt be familiar with much of the equipment and therefore should be able to operate in a good frame of reference. Mention of a specific product is not intended as an endorsement of that product. Nor does the omission of a particular product suggest that it is inferior to one which is mentioned. It should also be recognized that in general the equipment was not designed for the task to which we were assigning it. Hence, what might be judged a shortcoming for the present application may have little bearing on the equipment's ability to operate in the environment and provide the quality for which it was designed.

II. DEFINITION OF SYSTEM CHARACTERISTICS

The purpose of the gun-camera MDI is to provide an accurate estimate of the impact point of bullets fired in a simulated tactical situation. In order to perform this mission and not bias the results by altering the basic weapon characteristics it is necessary for the gun-camera MDI to meet certain performance criteria. To a large extent the required camera characteristics were dictated by the weapon. In some cases the requirements were somewhat more arbitrary and tend to reflect the engineering judgements of the authors.

The following lists the system performance specifications which were developed. Where appropriate, the rationale leading to the specification is outlined.

Weight: 0.75 pounds. The weight is the most difficult specification to meet. The .75 pounds value corresponds to the weight of the bayonet for the M-14 rifle. It is reasoned that replacing the bayonet with a camera will give a system of comparable balance and hence not adversely affect the user. Since the camera would not overhang the muzzle, as does the bayonet, it may be possible to exceed the .75 pounds slightly without creating a noticeable change in weapon dynamics.

Accuracy: 1 mil required, .5 mil desired. Accuracy in this context refers to the ability to determine where the weapon was actually pointed. It is primarily a function of the resolving power of the lens and film, although boresight accuracy and film reading are also factors. The ammunition has an inherent inaccuracy of about .5 mils linear standard deviation. Under a tactical situation aiming errors will probably be on the order of 5 mils linear standard deviation. Thus, if the total inaccuracy of the MDI system is .5 to 1.0 mils, the accuracy of the measurement will be about one order of magnitude more precise than the quantity being measured, namely aim error.

Cyclic Rate: 1 picture per second required, 3 pictures per second desired. The M-14 is normally rated at about 20-30 rounds per second for sustained fire. Therefore, one picture per second should be sufficient for most tactical situations. The maximum rate for aimed semiautomatic fire is thought to be 2-3 trigger pulls per second. Hence, 3 pictures per second would be a desirable characteristic.

Shutter Speed: 1/125 required, 1/250 desired. Measurements made by AAI indicate that the time of hammer travel from sear release to primer impact is .010 seconds. It is probably desirable to actuate the camera from the trigger and have the picture taken as shortly before bullet exit as possible. On the other hand, the shutter must close before bullet exit or the film will be over exposed by the blast. Hence a shutter speed in the .004 to .008 range is desirable.

Field of View: $\pm 5^{\circ}$

Number of Frames: 15 minimum

Film Transport: May be electrical or may use energy from recoil, gas cylinder, operating rod, or trigger so long as it does not adversely affect the operation of the weapon.

Bore Sighting: Should be accurate to .1 mils. Require capability to check in field. Desirable capability to adjust in field.

Fiducial Mark: Desired.

Film Size: 16mm or 35mm

Film Type: Consistent with exposure time and light level. IR sensitive acceptable for night operation. Daylight film loading in field desirable.

Illumination Levels: Day 3000-10000 foot candles
Dusk 1-10 foot candles
Night .005-.05 foot candles
If necessary, an IR source can be provided for night operation.

III. RESULTS OF INVESTIGATIONS OF ALTERNATIVE DESIGN APPROACHES

Four approaches to providing a gun camera were considered: an auxiliary powered still camera, a motorized pulse camera, fiber optics leading to a ground based camera, and a motion picture camera. Each concept was considered in terms of those special characteristics it offered which made it attractive as a gun camera, those characteristics which were undesirable, and those characteristics which were unacceptable.

Presently available equipment was used as a baseline. It was soon apparent that all of the systems were adaptable to some extent, but that weight was a serious problem. Using the present systems as a starting point, estimates were made as to what they would weigh if they were built without what were regarded as non-essential features such as adjustable focus lenses, viewfinders, frame counters, and CdS cell driven apertures. The results of this effort indicated that it appears feasible to build a miniature still camera along the lines of a commercially available one and have a sufficient weight margin to power the camera and mount it to the weapon. The other concepts were judged to be not feasible because of the stringent weight requirement. Details of the results of the investigation are given in the remainder of this section.

A. Still Camera with Auxiliary Power

The Minolta Company makes a series of subminiature 16mm cameras which we feel demonstrates the feasibility of making a camera which will satisfy the requirements established for the gun camera. The top of the line is the Minolta 16MG-S. Specifications for this camera are:

Lens: Rokkor-TD 23mm F2.8, 4 elements in 3 groups.

Shutter: 1/30 to 1/500 sec., X sync. contact at 1/30 sec., automatic diaphragm control by CdS electric eye. Shutter release automatically locks at over/underexposure.

Film and frame size: Instant loading Minolta 16 film magazine of 18 exposures, 12X 17mm.

Viewing: Brightframe viewfinder with parallax corrections: Over/under exposure warning signal visible in finder.

Exposure meter: CdS electric eye coupled to shutter and film speed setting.

Working range: EV8 to EV17. ASA(DIN) range: 25(15) to 400(27).

Film advance: Wheel type in 135° automatically cocks shutter and prevents double exposure.

Other features: Built-in lens cap turns off meter switch. Automatic resetting film counter. F-number scale on top of camera.

Size: 4-1/4"(L) x 1-1/16"(H) x 1-3/4"(D) (107.5 x 26.5 x 46mm).

Weight: 210g (7.4 oz).

A photograph of this camera is shown in Figure 1.

At the other end of the product line, Minolta offers a Model 16-PS. This camera has a 25mm f/3.5 lens with manual aperture adjustment and two shutter speeds: 1/30 and 1/100 second. Its dimensions are 4.06" x 1.06" x 1.62". The weight is 4.2 oz.

While these cameras as they are would not be suitable for the gun camera, they indicate the feasibility of building a camera along the same lines which would meet the design requirements. In particular the shutter and film transport of the 16MG-S model are of a type which would be desirable. The CdS cell and various exposure interlocking features are probably not needed. These features do not appear on the 16-PS model which results in a weight saving of 3 ounces.

Having ascertained that the construction of a 16mm camera within the estimated desired weight range was within the state of the art, attention was focused on the optics required to achieve the desired resolution and interfacing of the camera with the weapon. Photographs were made with 23mm and 58mm focal length lenses. These tests indicated that a lens in the 50-60mm range will provide the resolution necessary to achieve the accuracy goal. Details of these results are discussed in Section IV.

The shutter trip mechanism on a camera typically requires a force of a small fraction of a pound through a stroke of about .06 inch. Since we wish to coordinate the camera event rather closely with the functioning of the weapon, the most desirable design will use the motion of the trigger or trigger group to trip the camera. The M-14 has a hammer which makes a large sweep forward as it moves toward the firing pin. It should be possible to use the first part of this forward motion to push on a small flexible cable which would in turn depress the camera shutter trip. The amount of energy absorbed would be quite small and should not affect the performance of the weapon.

MINOLTA 16MG-S CAMERA

FIGURE 1

The Minolta cameras had a desirable feature in that the film advance also cocked the shutter. Thus, besides tripping the shutter, only one other motion must be imparted to the camera. The Minolta 16MG-S has a 1.2 inch diameter wheel which must be turned to transport the film and advance the shutter. A motion of 135^{o} is required. The torque required was measured to be .45 inch-pounds. This is the torque required to overcome stiction and internal spring forces. It is estimated that a torque of about 1 to 1.5 inch-pounds would be required to move the wheel fast enough to get a firing rate of 3 pictures per second. There are several means of achieving this torque. A constant torque Neg'ator spring B motor which supplies 1.2 inch-pounds of torque through 15 revolutions can be made for a weight of less than .1 pounds. In operation, the spring would be wound up with a key after the film had been loaded into the camera. There would be enough travel to accommodate one roll of film. There are other energy sources available in terms of the recoil of the weapon, the gas cylinder, and the operating rod. The energy required to advance the film is modest so that tapping the recoil cycle would not affect the weapon. However, the onset rate of the force may be excessive. In a detailed design of the gun camera all of these approaches should be evaluated in terms of weight, reliability, and complexity.

The camera would be mounted to the barrel of the weapon with an aluminum or magnesium fitting. Adjustments would probably be made by shimming the camera into place or perhaps with set screws. There is enough weight allowance remaining for several cubic inches of material so a reasonably rigid mount should be possible.

Based on the results of this preliminary investigation it is concluded that it is possible to build a gun camera, using presently available technology, which will meet the design goals. The system would consist of a miniature 16mm camera with a fixed focus lens of approximately 58mm focal length, and a shutter speed of 1/250 seconds. Shutter trip would be interfaced with the trigger and film advance and shutter cocking would be derived from a spring or the weapon. An estimated weight breakdown for this system is:

Camera	.35 lb
Film transport	.15 lb
Shutter trip	.10 lb
Mount	.15 lb
	.75 lb

B. Pulse Camera

There are a variety of motor driven pulse type cameras on the market. This concept has appeal in terms of minimal development because in theory one would simply have to mount an existing camera on the weapon and interface it with the trigger.

The Bell & Howell Models 200P, 917F, and KD 7 are designed to operate on 28-volt direct current and are representative of the 16mm pulse type camera used in data recording. These cameras, with the exception of Model 200 P, operate in two modes, pulse or cine. In pulse operation the exposure rate and duration is controlled by the externally applied pulse. In cine-operation the camera functions continuously at 8 or 12 frames per sec, depending on the particular model. Maximum rate of pulse operation is 7 or 8 exposures per sec.

The Model 200 P, which accepts standard 50-ft film magazines, operates at a maximum pulse rate of 8 exposures per sec and minimum exposure time of 1/100 sec. A pulse length of 30 msec is required to obtain this shutter speed. A rotary disk shutter with a 180° opening stops in the normally closed position.

Model KD 7, operable at 12 frames per sec as a cinecamera or at a maximum of 10 frames per sec pulse, holds a magazine of 50-ft capacity. A pulse 20 to 65 msec in duration is required to operate the camera.

The Dekko type N 16-mm camera, marketed by Benson-Lehner Corporation, operates 0 to 6 frames per sec in pulses or 8 to 150 frames per sec continuously as a cinecamera using 28-volt d-c interchangeable motors and a three-speed gear box. The camera accommodates magazines of 50-, 100-, and 200-ft capacities.

The Flight Research Model III 16mm Multidata camera operates at 4 to 64 frames per sec as a cinecamera or up to 20 frames per sec as a pulse camera.

The primary difficulty with these cameras in terms of using them as a gun camera is the weight. They fall in the 2 to 4 pound category and it is doubtful that the weight of an existing camera could be reduced to the design goal of .75 pounds. For this reason this approach was considered not feasible.

C. Fiber Optics

The use of coherent fiber optic light guide offers an alternative to the direct mounting of a camera to the weapon. The fiber optic offers a method of mounting a lens on the weapon and transferring the image through a flexible shaft to a camera located on a separate mount. A typical device is the American Optical Model FS-163 Fiberscope which is shown in the following literature. The fiberscope is mechanically designed to accept standard "C" mount lens at the input and a relay lens at the output for direct coupling to a camera.

The objective lens and input end of the fibers would be hand mounted to the weapon. The output end of the fibers are coupled to a camera such as a Nikon F 35mm with self-contained electric drive film advance. This camera is capable of a maximum 4 frames per second.

The trigger sensor to activate the camera shutter can either be electrical or mechanical, sensing the sear release of the hammer.

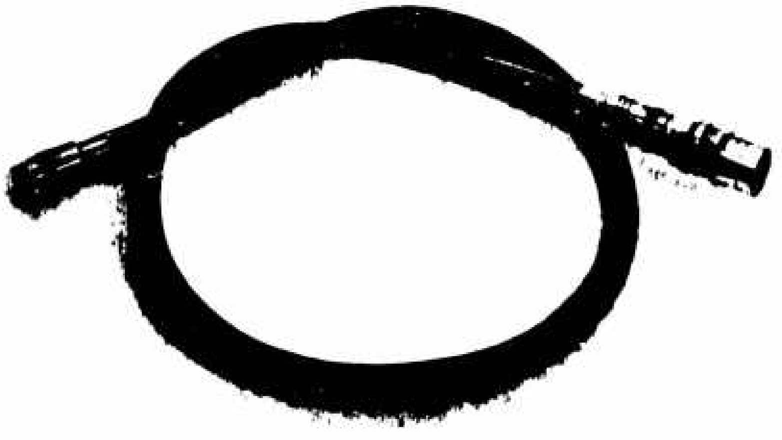
While in theory this method may be attractive, in practice there are some severe limitations. The most severe drawback is the weight of the fiber itself, exclusive of objective and relay lens. For the FS-163-36, a 36-inch Fiberscope, the weight is approximately 7 lbs. Even with the weapon supporting part of this weight, the desired .75 lb maximum, exclusive of objective lens, would be exceeded.

The Fiberscope is flexible; however, the minimum bend radius of 6 inches would still cause some restrictions to the gunner's motion ability.

The fiber system has inherent light loss of approximately 60% in a 3 ft. length. While this can be compensated, it still is extra loss on the system. Similarly, the resolution capability of 50 line pairs/mm is quite good for a fiber device but still represents an additional loss before getting to the film.

It is concluded that the use of a coherent fiber optic light guide is not feasible because of the weight associated with it.

AO FIBER OPTICS



MODEL FS-163 FIBERSCOPE

The FS-163 Fiberscope is designed to provide high quality visual information from remote locations. This versatile fiberscope can be used as an inspection instrument or as a flexible extension for a motion picture or TV camera, and the large 8 x 10 mm. fiber bundle (in lengths up to 12½ feet) provides unmatched optical performance.

The FS-163 has been used extensively in aerospace applications in areas where mounting a TV or cine camera would be impossible because of space limitations, vibrations, temperature fluctuations or hazardous atmosphere. These applications have included photographic instrumentation in the Atlas and Saturn missiles, jet engine test stand instrumentation, monitoring of electron beam welding, stereo photo interpretation, rocket fuel core inspection, and observation of surgical and operating room procedures.

This unique capability to transmit an image with high color fidelity through a flexible path is made possible by the use of American Optical Multifibers. Each fiber contains 36 individual 10-micron elements which transmit an image through the fiberscope by internal reflection. There are more than 675,000 fiber elements in this unit with a resolving capability of 50 line pairs per millimeter.

For photo-optical coupling, the FS-163 is equipped with standard "C" mounts and can be connected easily to a 16 mm. cine or vidicon camera with the FS-1650 relay lens. If the fiberscope is used for visual inspection, a 10X eyepiece is available. In either case, 25 mm. or 50 mm. objective lenses are available as standard accessories.

One end of the fiberscope is equipped with an integral rotating adjustment. This permits orientation of the fiber bundle format without having to move the whole fiberscope. The fiber bundle is protected by a rugged but flexible sheathing of braided stainless steel with a teflon liner.

FS-163 SPECIFICATIONS

Image format	8 x 10 mm.
Multifiber cross section	60 microns (.0024")
Individual fiber diameter	10 microns
Resolution (typical)	50 line pairs/mm.
Coherency	± .0024" maximum deviation
Fiber breakage	.5% maximum
Number of fibers	675,000 (nominal)
Fiber acceptance angle	60° included
Distal O.D.	1.3" maximum
Radius of bend	6" minimum (inside)
Bundle rotation inside sheathing	±150°

ORDERING INFORMATION

Catalog No.	Parts & Accessories
FS-163-24	2-foot fiberscope
FS-163-36	3-foot fiberscope
FS-163-48	4-foot fiberscope
FS-163-60	5-foot fiberscope
FS-163-72	6-foot fiberscope
FS-163-108	9-foot fiberscope
FS-163-150	12½-foot fiberscope
FS-16-EP	10X eyepiece
FS-1610	25 mm. objective lens
FS-1620	50 mm. objective lens
FS-1650	AO relay lens (1:1)
FS-16-RA	Right angle prism for FS-1610 lens

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D. Motion Picture Camera

A motion picture camera appears to offer advantages in terms of simplicity and reliability. If the camera is battery or externally powered, the gunner would simply turn on the power and commence firing. The muzzle flash would register as an overexposure and the analyst would simply back up one frame to get a picture of where the weapon was pointed just before bullet exit. A further potential advantage of this system is that a continuous record of aim point wander would be made. It would appear that this information may have value from a human engineering standpoint.

The major difficulty with the motion picture camera is weight. Agfa offers a battery powered super 8 camera which will take 50 feet of film. It has a 2.5 power zoom lens. It is approximately 1 inch wide, 3 inches high and 6 inches deep. This unit weighs approximately 1.3 pounds with the film. While it should be possible to reduce the weight by .1 or .2 pounds by replacing the zoom lens with a fixed one and some selected machining of the body, these savings will be lost in the hardware required to mount the camera to the weapon. Hence, a system weight of about 1.3 pounds would be expected. This exceeds the design goal of .75 pounds by a considerable margin.

In the 16mm size D.B. Milliken offers a model DBM-2A gunsight camera. A brochure describes it as the "smallest gunsight camera built." The camera has film speeds to 48 pictures per second and a 50mm lens. It requires 28 volts DC to drive it. The camera is 1.25" wide, 3.25" high and 8.65" deep with a 50-foot magazine. The camera with lens and motor weighs 1.0 pounds. The magazine weighs 0.6 pounds and the film is 0.26 pounds. Hence, it is estimated that a mounted weight would approach 2.0 pounds.

Our investigation indicated that these cameras were representative of the lightest models currently available. Their weight exceeds the design goal by such a large amount that in our opinion this concept has at best border-line feasibility.

IV. RECOMMENDATIONS

Based on the results of this preliminary feasibility study it is concluded that it is apparently feasible to develop a system, using present technology, which will meet the goals of the gun camera MDI. It is recommended that the development of the system be initiated.

The following is offered as a recommended design approach and rationale.

Basic Camera: The basic device should use 16mm film, have a fixed focus lens and a shutter speed of 1/250 second. The camera should be devoid of unnecessary interlocks or automatic features commonly found on commercial equipment because of the weight penalty.

Mounting: There should be approximately .15 pounds available for the mount. Aluminum and magnesium are likely candidate materials. Detailed analyses should be made to insure adequate stiffness. The effects of barrel heating on dimensional stability and alignment should be considered.

Film Advance: The film advance mechanism should be rugged and require as little motion as possible. It is desirable that the film advance also cock the shutter. The energy source for transporting the film could be a spring, weapon recoil, or the recoil cycle of the weapon. All of these modes should be considered in light of minimizing weight and the stresses imposed on the camera. A film advance rate of 3 pictures per second is desired.

Shutter: The exposure of the film must be closely coordinated with the weapon so that it gives an accurate estimate of the boresight and is not overexposed. Using the motion of the hammer to open the shutter is recommended because it is beyond the gunner's control and is accurately reproducible. The duration of hammer travel is .010 seconds; hence, an exposure time of .004 seconds (1/250) appears desirable. This time is compatible with the film characteristics. A small solenoid with a microswitch in the trigger group, or a mechanical flexible cable are two methods of actuating the shutter. The mechanical approach may be desirable from a weight standpoint. Since this weight would be distributed uniformly along the length of the barrel rather than concentrated at the end, a relatively heavy cable could be used with no noticeable effect on the weapon.

Lens: It is recommended that the lens be of good optical quality, have a focal length of 50 to 60mm, and an f/4 aperture.

Because of the crucial nature of this recommendation in terms of system size, tests were run to experimentally determine the resolution of capabilities of two lens-film combinations. A 35mm single lens reflex camera with a 58mm focal length lens and a 16mm miniature camera with a 23mm focal length lens were used with plus-X film. High contrast three-bar resolutions charts, hand held, were used as the targets. The target characteristics are shown in the following table.

Target No.	Bar Width	Bar Height	Target Outline
1	1.44 in.	7.20 in.	10.08 x 10.08"
2	2.14 in.	10.70 in.	14.97 x 14.97"
3	2.88 in.	14.40 in.	20.16 x 20.16"
4	4.28 in.	21.40 in.	29.96 x 29.96"

(Target is a high contrast black bars on white background.)

The targets were photographed at ranges of 100, 200, 300 and 400 meters using the cameras hand held. Tripods were not employed. The pictures obtained, therefore, represent a realistic resolution that could be obtained with a final system. The effects of atmospheric scintillation and motion of the camera, both of which are present, degrade the theoretical resolution but must be included to give a time measure of the practical system capabilities.

All exposures were taken with the cameras set at 1/250 second and F/11 lens opening which is typical for plus-X film on a bright sunny day. Accufine, a fine grain developer, was used in the development. The test range was a field of low brush with various objects throughout.

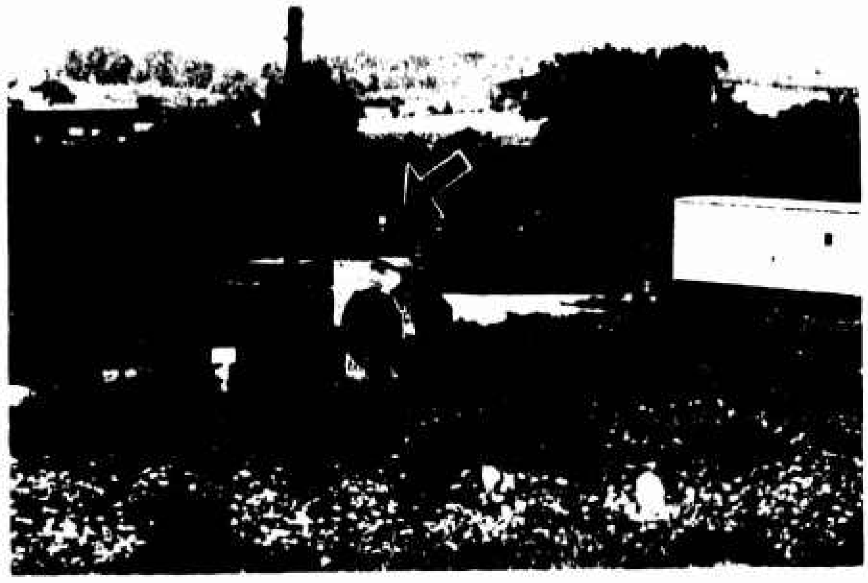
The first set of photographs are those taken with the 35mm camera at a range of 400 meters. The original negative was enlarged by 10X and cropped to the field of interest. In the reproduction process detail has been lost. The arrow points to the target being held over the head of a standing person. In the original negative the three bar chart is resolvable on targets #3 and #4. At 400 meters the 2.88 inch bar (target #3) amounts to an angular resolution of 0.18 milliradians.

The measured resolution of the 16mm camera in line pairs/mm was equivalent to the 35mm camera; however, because its focal was 23mm as compared to 58mm for the 35mm, its angular resolution is decreased by a factor of 60%. Photographs of the tests run at 200 meters with the 16mm camera are shown for comparison.

TARGET #1 58MM LENS RANGE = 400 meters

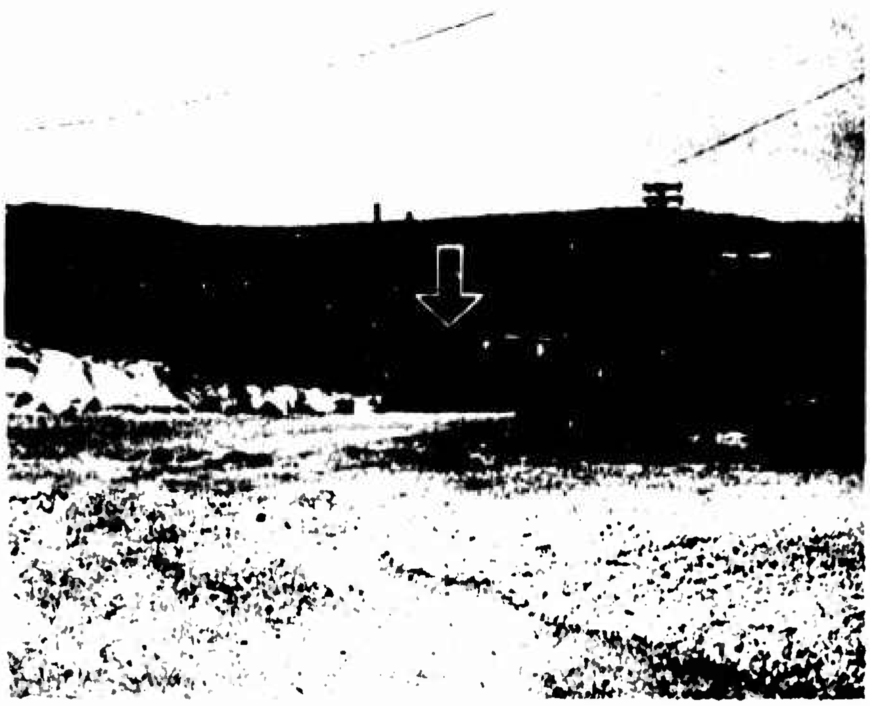
TARGET #2 58MM LENS RANGE = 400 meters

TARGET #3 58MM LENS RANGE = 400 meters



TARGET #4 58MM LENS RANGE = 400 meters

TARGET #1 23MM LENS RANGE = 200 meters



TARGET #2 23MM LENS RANGE = 200 meters

TARGET #3 23MM LENS RANGE = 200 meters

TARGET #4 23MM LENS RANGE = 200 meters

Film: It is well known that there is a considerable amount of art in the science of film processing. This will in turn influence the quality of the results. Using good practices both plus-X and Tri-X film have a theoretical resolving power of better than 100 line pairs per millimeter. This resolving power, coupled with the proper lens, will permit the desired system accuracy. In general, slower films tend to have a finer grain structure. Also, the theoretical resolving power of a given lens improves as the aperture size is increased. Hence, use of the slowest film possible for given lighting conditions is desirable.

Field Loading: The film for the Minolta cameras comes in plastic cassettes which permit daylight loading. A similar design is desirable for the gun camera. The relatively rapid film transport rates may require a design more rugged than commercial units exhibit.

Night Operation: At 1/250 second exposure time and f/2.8 Plus-X film requires 52 foot lamberts luminence from the target for proper exposure. For a reflectance comparable to skin, 0.3, the incident illumination required is 173 foot lamberts. If Tri-X film is used this minimum value is 54 foot lamberts.

The night operation of the camera system will require certain modifications from the daylight setup. At night some form of artificial lighting of the target will be required to expose the film. Any form of visible illumination of the target would negate the experiment since it creates an artificial situation for the gunner. A more acceptable method is to use IR sensitive film in the camera and illuminate the target with IR illumination in a manner similar to the old Snooperscope.

The Kodak High Speed Infrared film has a 160 ASA rating when a Wratten 25(A) filter is used on the camera. For an estimated shutter speed of 1/250 second and an F/4 lens setting, this will require an average target brightness of 83 foot lamberts. This illumination could easily be produced by illuminating the target source a few feet in front of target. The source could be battery operated and only turned on when the target is in the erect position. A metal shield can be placed over the source as a protective device.

The resolution of the IR film is approximately 25 line pairs/mm which is less than the plus-X; however, it should be sufficient for engagements up to 500 meters, although the resolution will be poorer than in the daylight.

Boresighting: The alinement of the camera will be done so that it is parallel to the bore of the rifle.

To accomplish the boresighting of the camera it must be modified to add a Fiducial mark or reticle just before the film plane. The reticle will be close enough to be in focus on the final film image and define the actual aim point of the camera. To boresight the camera to the gun the back of the camera must be removed and a lens eyepiece attached will focus on the reticle-film plane. This effectively makes the optical system low power telescope with reticle for accurately setting the camera aiming direction.

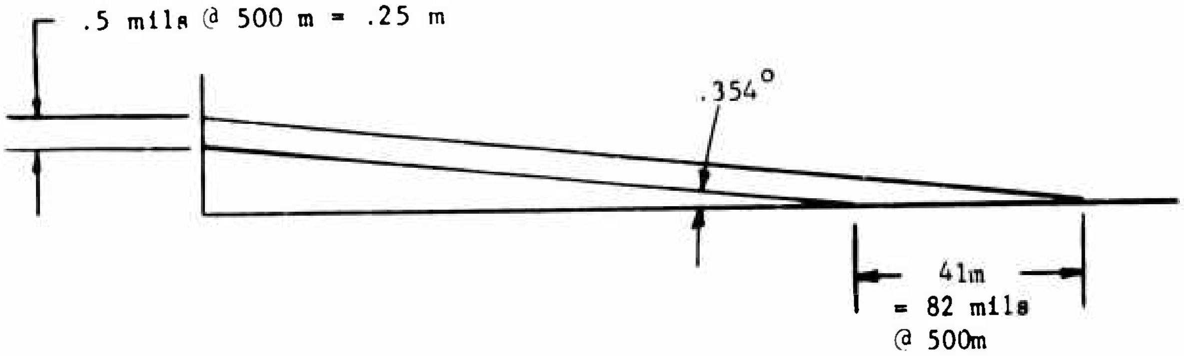
The camera will be mounted to the rifle with an adjustable mount to facilitate the alinement.

The procedure to aline either in the laboratory or in the field is straightforward. With the rifle rigidly supported, a small mirror can be used in the breech to view down the barrel. Using the circular apertures of the two ends of the barrel, the barrel can be used as a pin hole collimator. By sighting down the barrel a distant object can be chosen as a reference. Using the eyepiece on the camera the center of the reticle can be sighted in on the same distant object. The eyepiece can then be removed and the film installed.

It should be recognized that by aligning the camera with the bore of the weapon the picture will show where the weapon was pointed rather than where the bullet landed. This is due to the ballistic drop of the bullet. It is not possible to align the camera with the impact point because the targets will be placed at varying ranges, thus the drop is not a constant. Part of the data reduction procedure will include subtracting the bullet drop. As an indication of the magnitude of this drop, 4.68 mils superelevation is required with the M-14 rifle firing M-80 ball ammunition at a 500 meter target. Thus, the weapon is pointed 2.34 meters above the target. It may also be necessary to correct for drift and windage at the longer ranges.

Expected Accuracy: Based on the tests conducted during this investigation it is expected that the location of the point of aim of the barrel with respect to the edge of a target at least 10 inches square at a range of 500 meters can be determined to an accuracy of .5 mils or less using a lens of acceptable size. It should be noted that this measurement is in the plane of the film and therefore applies to a miss distance in the vertical plane. For near horizontal firing the impact point on the ground changes drastically for small changes in height. At 500 meters an M-80 bullet has an angle of fall of $.354^{\circ}$ and a velocity of 1801 feet per second. As shown in the sketch on the following page, an error of .5 mils in the vertical plane leads to an error or 82 mils in the computed impact point in the horizontal plane.

This condition should be considered if the gun camera system is to be used to estimate ground impact points as well as miss distance in the vertical plane. The potential error involved diminishes as the gunner is elevated above the target.



Summary Of Recommended System Specifications

Camera Size	:	16mm
Focal Length	:	50-60mm
Number Of Pictures	:	15-20
Pictures Per Second	:	1 Required, 3 Desired
Maximum Weight	:	.75 Pounds
Shutter Activation	:	From Trigger
Film Transport	:	Spring or Weapon Powered

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13. ABSTRACT A study was made to determine the feasibility of mounting a photographic device on a rifle so as to obtain a picture of the boresight point just prior to projectile exit. The photograph would be used to estimate projectile miss distance at ranges up to 500 meters under simulated tactical conditions. During the program the desired system performance specifications were established and alternative design approaches were evaluated.

It was concluded that it is apparently feasible to build a device, using present technology, which will meet the performance specifications. It is expected that the most difficult specification to meet will be the .75 pound weight limit, which corresponds to the weight of a bayonet for an M-14 rifle.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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